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MULTIPLE-CHANNEL CONDUCTOMETER FOR MEASURING SALINITY CONCENTRATIONS IN LABORATORY FLOWS

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Iowa Institute of Hydraulic Research

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A multiple-channel conductometer for measuring salinity concentrations in laboratory flows is described. Channel-to-channel influence and sensitivity to extraneous grounds have been reduced to acceptable levels by a unique probe excitation and detection system which keeps the fluid at ground potential. Conductivity rather than resistivity is measured to eliminate nonlinear concentration-voltage relationships, and special circuits are included to make calibration curves independent of the cable length between probe and instrument. The system has been designed with outputs suitable for analog and/or digital processing and with emphasis on ease of operation and reliability. The electronic system utilizes operational-amplifier technology jointly with discrete components to optimize signal processing and to take advantage of recent advances in the electronic industry.

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The University of Iowa
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Abstract of

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by

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A multiple-channel conductometer for measuring salinity concentrations in laboratory flows is described. Channel-to-channel influence and sensitivity to extraneous grounds have been reduced to acceptable levels by a unique probe excitation and detection system which keeps the fluid at ground potential. Conductivity rather than resistivity is measured to eliminate nonlinear concentration-voltage relationships, and special circuits are included to make calibration curves independent of the cable length between probe and instrument. The system has been designed with outputs suitable for analog and/or digital processing and with emphasis on ease of operation and reliability. The electronic system utilizes operational-amplifier technology jointly with discrete components to optimize signal processing and to take advantage of recent advances in the electronic industry.

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MULTIPLE-CHANNEL CONDUCTOMETER FOR MEASURING SALINITY CONCENTRATIONS IN LABORATORY FLOWS

I. INTRODUCTION

The measurement of electrical conductivity between two electrodes immersed in flowing water containing a small concentration of dissolved salts depends on the concentration of the electrolyte, the temperature of the water, and the velocity of the water flowing past the sensing elements. Before the elimination of or the correction for the contribution provided to the total signal by each of these variables can be made, the source and degree of influence of each must be determined. For example, sensitivity to velocity is caused by heat transfer from the surface of the electrodes and is reducible to an acceptable level by keeping the probe voltage at a minimum. Likewise, the influence of temperature changes can be compensated for by measuring temperature simultaneously with conductivity and electronically adjusting the output to be independent of temperature.

The principal difficulty associated with the type of probe and method of excitation utilized for measuring conductivity is channel-to-channel interference when multiple probes are used simultaneously in the same fluid system. One of several causes of this interference can be attributed to the nonlinear distribution of resistance between the two electrodes (the resistance is largest in the immediate vicinity of each electrode). The introduction of a secondary ground (assuming that one electrode of the probe is grounded) causes a change in the indicated resistance of the fluid because it provides another path for the current coming from the positive electrode. This secondary ground changes the effective area of the grounded electrode and thereby the properties of the probes so that a lower resistance is indicated. As a consequence, differences between the conductivity of the samples measured in the flume and in glass containers are observed. Elimination of secondary grounds in a laboratory flume is, of course, very difficult. Although probes have been developed which concentrate the resistance at one

electrode, channel-to-channel interference may still be present unless identical voltages exist on all electrodes.

A second cause of channel-to-channel interference is independent probe excitation which creates harmonics in the signal representing conductivity. This interference is easily removed by using a common oscillator to drive all probes.

Since the need for multiple-channel measurements arises in studies involving diffusion and dispersion of saline solutions in fluid systems, the elimination of channel-to-channel interference was absolutely necessary. As a result, a technique for operating probes simultaneously in the fluid system has been developed along with a unique probe-current detection network to provide a linear relationship between the signal indicated and conductivity.

II. THEORY OF OPERATION

Probes commonly used for conductivity measurements have two similar electrodes in very close proximity to each other. Concentration measurements are then based on the resistance, which is concentrated in the immediate vicinity of the electrodes, measured between the two electrodes; thus, the voltage drop between the two electrodes takes place at two primary locations: the two surfaces surrounding the electrodes. If the electrodes are assumed to be symmetrical, the potential of the fluid midway between the two electrodes is one half the total voltage applied to the probe. Unless this voltage is zero relative to system ground, current will flow between the electrodes and any ground. The easiest method for eliminating fluid potential is to provide balanced excitation to the probe (i.e., voltages of equal magnitude but opposite phase are applied to the two electrodes). This method, however, insures zero fluid potential only if the electrodes in the probe are identical. Figure 1, which represents the resistance of two electrodes and an extraneous ground, suggests a technique for reducing secondary ground effects. When the two electro resistances, R_1 and R_2, are equal, current will not flow through resistor

R_3, and the currents in both electrodes will be identical. More realistically though, R_1 is not equal to R_2 and a current will pass through R_3. For the condition in which R_1 is greater than R_2, the current in R_1 will decrease while that in R_2 will increase. Although the current increase in R_2 does not equal the current decrease in R_1, the percentage change in the sum of the two currents is less than the percentage change of the current in the individual electrodes. Therefore, direct measurement of the sum of the currents in the electrodes reduces the influence of secondary grounds. In addition, direct measurement of the sum of the currents in the electrodes provides a signal proportional to salinity concentration for low concentrations of salt.

Normal techniques for making conductivity measurements are not suitable because they do not function over a sufficiently wide current range and conflict with the balanced probe excitation requirement. The circuits described herein were developed to circumvent these problems. Extensive use is made of integrated-circuit operational amplifiers, because of their ease of incorporation and of their excellent performance. Discrete components are used in the current detecting network because access to their counterparts in IC amplifiers is not possible. These design considerations have resulted in an instrument which is very reliable, is easy to operate, and does not require extensive operator training or experience.

III. CIRCUIT DESCRIPTIONS

A. Range and Shield-Driving Networks. Figure 2 is an abbreviated schematic of the range and shield-driving networks. Amplifier A1 operates in conjunction with resistors R_8 through R_{15} and the range switch to adjust the voltage supplied to the probe, and hence the sensitivity of the instrument. The amplifier input resistor, R_{15}, is connected to the output of the oscillator. Resistors R_8 through R_{14} are individually selected as the feedback resistor by the range switch to control the probe voltage. Amplifier A2 inverts the output of amplifier A1 to provide the inverted signal used to drive the second electrode in the probe. This method of ranging reduces the power dis-

sipated in the probe as conductivity increases, and was selected to minimize the velocity sensitivity characteristic mentioned above.

Because the probe excitation-detection network also supplies and responds to the current necessary to drive the capacitance in the cable connecting the instrument with the probe, a cabling arrangement different from those usually utilized was selected. Each electrode in the probe is connected to the instrument by a shielded conductor, and the influence of conductor-to-shield capacitance is eliminated by supplying the shield with a voltage of magnitude and phase equal to that driving the conductor (i.e., the voltage applied to the electrode). The voltages driving the shields are derived from a secondary source which is independent of the excitation-detection network. Since there is no voltage drop between the conductor and shield, the detection network is not influenced by cable capacitance. Amplifiers A3 and A4 in figure 2 serve to supply the appropriate voltage to each of the two shields.

B. Probe Supply and Detection Network. The probe supply and detection network is shown in figure 3. The two sinusoidal signals having a phase shift of 180° relative to one another are connected to the positive inputs of amplifiers A5 and A6. These signals are the outputs of amplifiers A1 and A2 shown in figure 2. Transistors Q_1, Q_2, Q_3, and Q_4 associated with amplifiers A5 and A6 provide the current gain necessary to operate the probe. The transistor stages are designed for class B amplifier operation and, as is seen in figure 3, transistors Q_1 and Q_3 share a common collector resistor. Since the operation is class B, transistor Q_1 conducts during one half of the cycle and Q_2 conducts during the other half of the cycle. Because of the 180° phase difference, the conducting cycles of Q_1 and Q_3 do not overlap and the signal on the collector resistor shared by Q_1 and Q_3 is the rectified signal proportional to the current passing through the probe. Monitoring this signal without influencing probe current is possible because the measurement is accomplished within the feedback loop controlling the voltage delivered to the probe rather than external to the feedback loop. Hence, this very simple circuit not only provides an efficient means for measuring probe current, but also supplies the balanced ex-

citation required to reduce channel-to-channel interference and sensitivity to extraneous grounds.

C. Butterworth Filter Network. The filter for reducing the ripple of the rectified signal is an active third-order Butterworth filter (see figure 4). The network has a gain of ten over the frequency spectrum of DC to 100 Hz. Attenuation is -3db at 1000 Hz. and -60 db at 10,000 Hz., the probe excitation frequency. Resistors R_{25} and R_{26} serve as a second input to the amplifier and provide the bias necessary to offset the quiescent voltage level of the collector resistor shared by Q_1 and Q_3. The output of the amplifier is connected to a DC milliammeter through an appropriate resistor.

The circuits described above represent one channel of a multiple-channel system. The oscillator supplying the reference voltage for the range and shield-driving networks is utilized by all channels. Likewise, the supply voltages for operating the operational amplifiers are supplied by a common power supply.

IV. CALIBRATION

Calibration of the system to obtain the relationship between output voltage and concentration of electrolyte is required for each probe. This is most conveniently accomplished by preparing a number of samples with known concentrations covering the concentration range to be measured. Each probe should be immersed individually into all of the solutions and the output voltage or meter deflection recorded for each one. Once a calibration curve for each probe is obtained, all probes should be calibrated simultaneously for each of the solutions. This simultaneous calibration provides the check necessary to insure that minimum channel-to-channel interference is present. Figures 5 and 6 show typical calibration curves for two different ranges of concentration. The slope of the various calibration curves is adjustable by the range switch and gain control. Likewise, the output voltage or meter deflection of the conductometer may be set to zero for zero concentration.

Calibration of the instrument in terms of conductance is accomplished by replacing the probe with a precision decade resistor. Results of this type of calibration are shown in figure 7 for range position 1. The approximate minimum conductance necessary to cause full-scale deflection on the most sensitive range is 120 micromhos. Full-scale deflections for the other positions of the range switch scale in a one-two-five-ten sequence relative to the most sensitive range.

V. CONCLUDING REMARKS

The problems associated with the measurement of electrical conductivity described in this report were recognized for a specific experimental application. Circuits were designed to minimize their influence and to permit the simultaneous acquisition of data from several points in a recirculating flume. The instrument has been used for a period of one year without failure and without indications that the design has introduced other undesirable characteristics. As a result, it would appear that the multichannel conductometer described in this report is well suited for experimental studies requiring simultaneous measurements of conductivity.

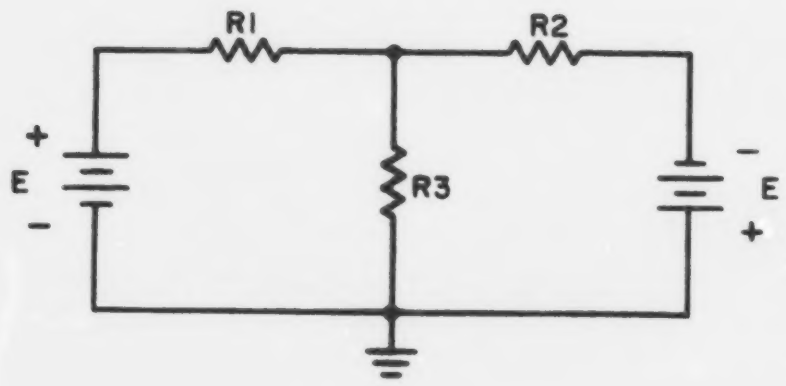

Figure 1. Probe Equivalent Circuit

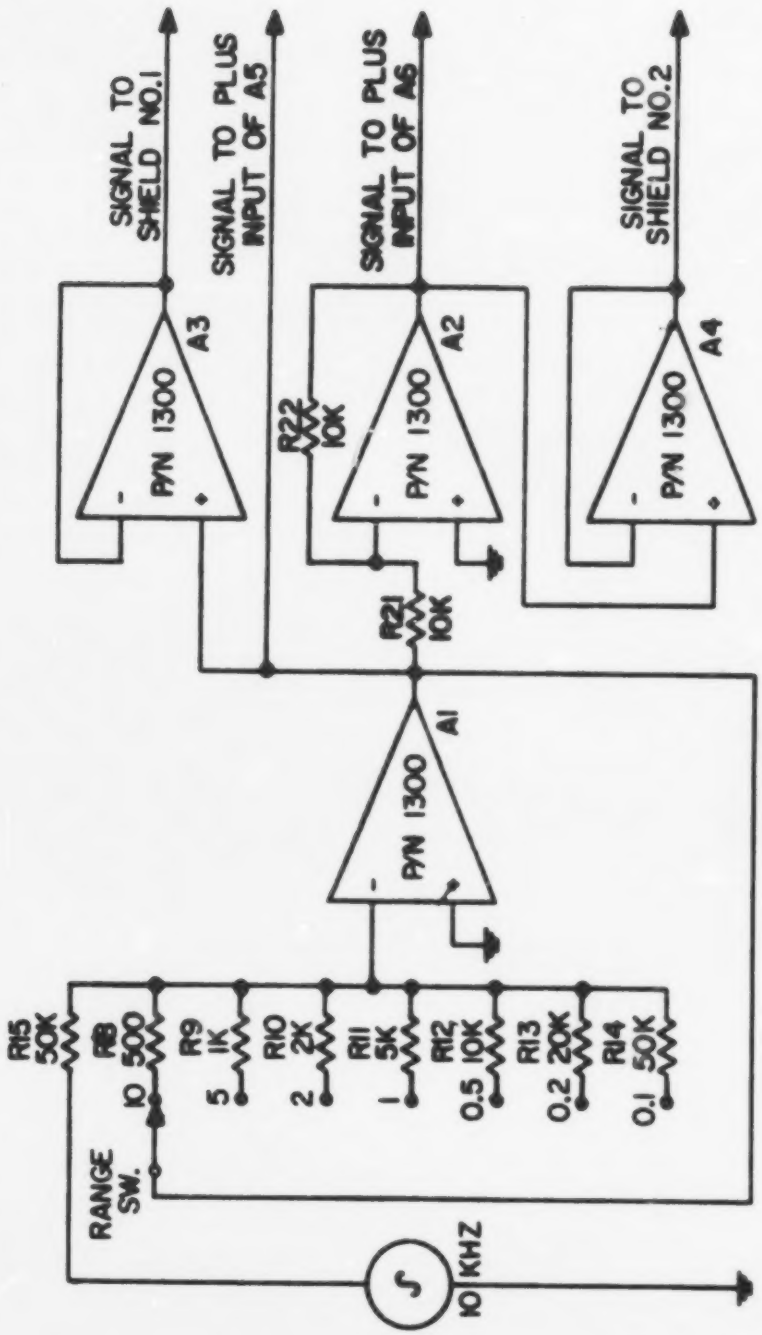

Figure 2. Range and Shield-Driving Networks

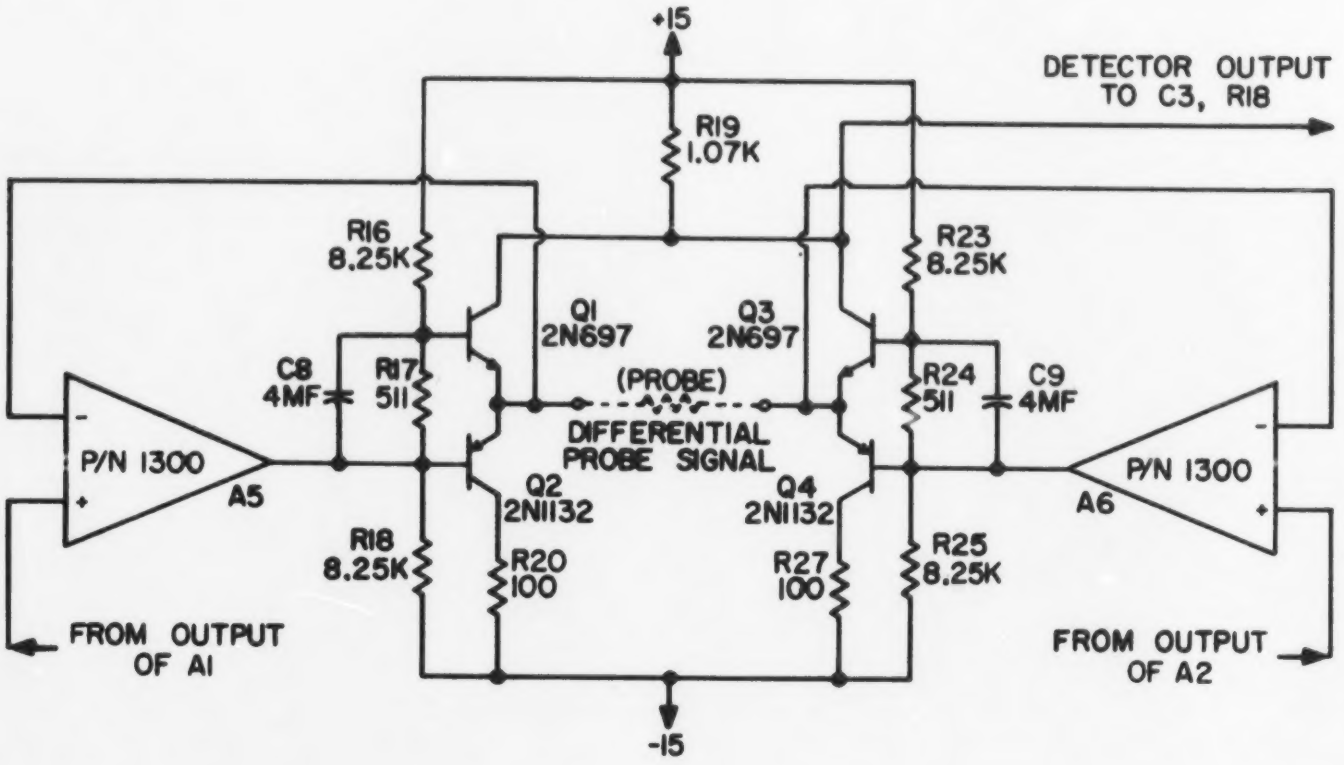

Figure 3. Probe Supply and Detection Network

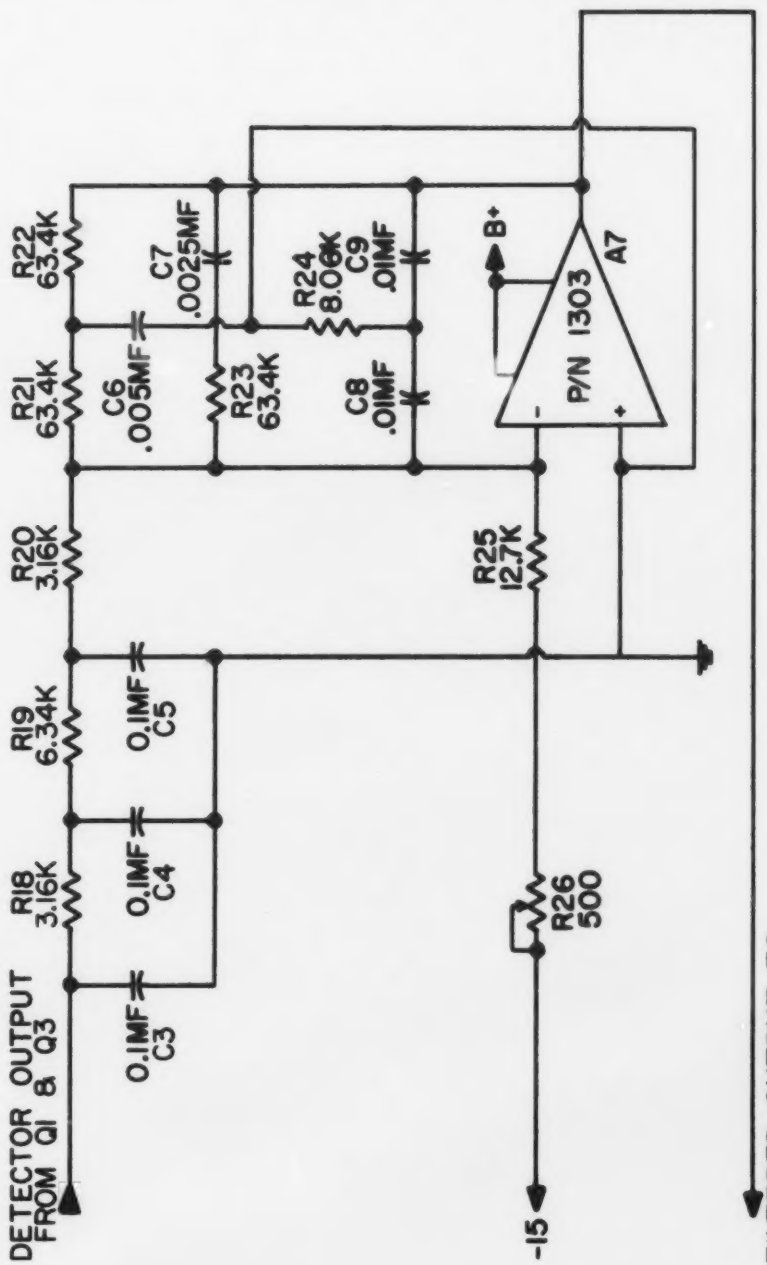

Figure 4. Third-Order Butterworth Filter

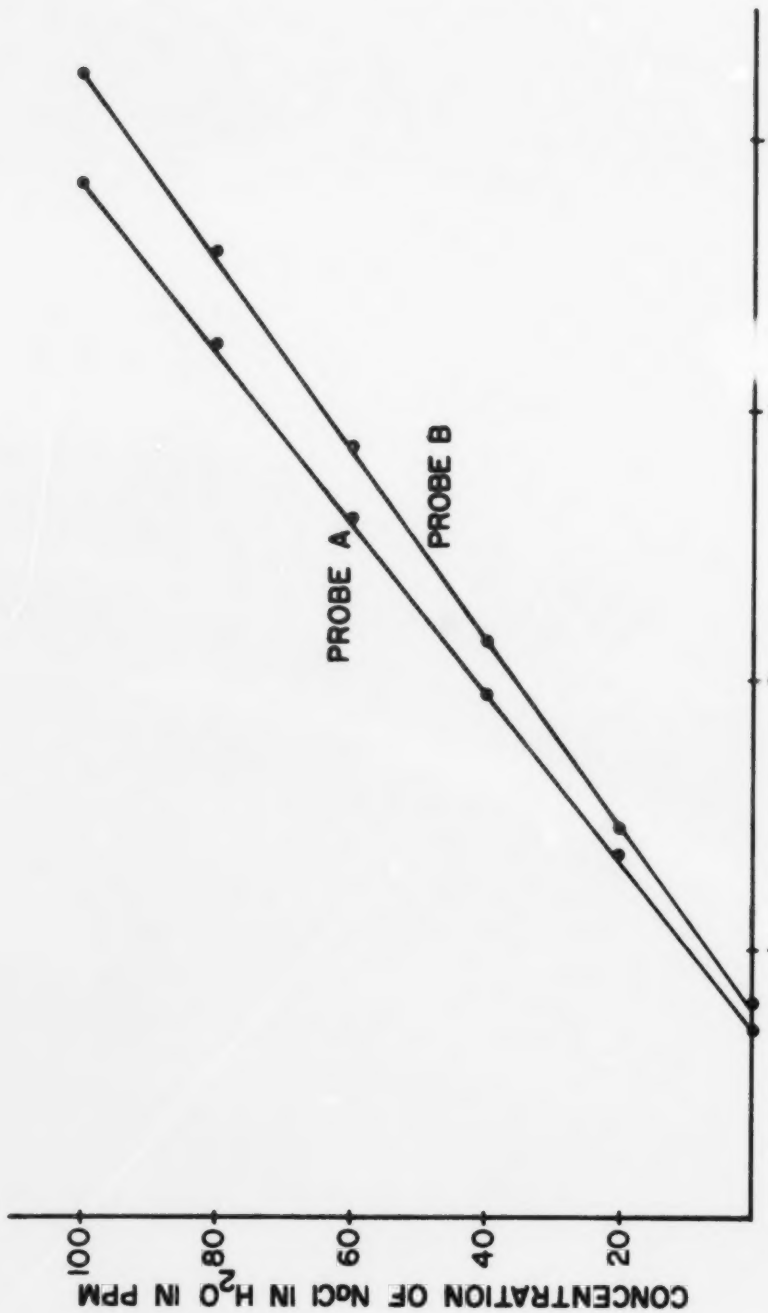

Figure 5. Typical Calibration Curve For Low Concentrations

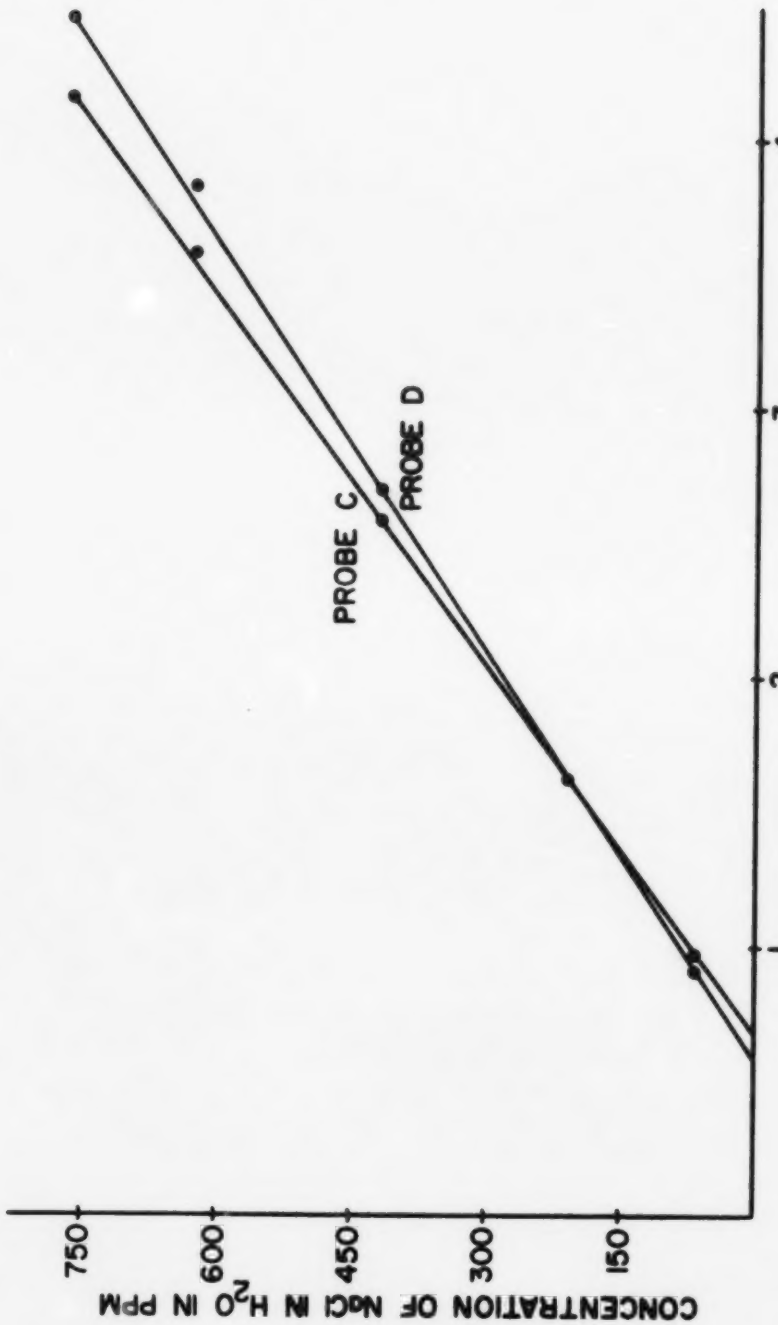

Figure 6. Typical Calibration Curve For High Concentrations

Figure 7. Conductance Calibration Curve

APPENDIX A

I. PROBE CONSTRUCTION AND PLATINIZING PROCEDURE

Probe construction requirements are not rigid provided two identical electrodes are incorporated into a single probe. The main points to be observed in probe construction are: 1) that it be suitable for the platinizing process; 2) that it be as large as possible; and 3) that it be as rugged as possible. Platinum electrodes suitable for platinizing are generally mounted in glass and extend from the probe body sufficiently far to ensure that the platinizing solution does not come into contact with anything except the platinum electrodes and supporting glass. The size of the probe is determined by the experimental apparatus and is directly related to the ruggedness and sensitivity of the probe.

The circuits for cleaning and platinizing the electrodes are shown in figure A1. The main difference between these two circuits is the polarity of the battery. Preparation of the solutions is described at the end of this section.

Preparation of the electrodes for the platinizing process consists of the following steps:

1. Heat the platinum-foil electrode white hot, permit the electrode to cool, and then thoroughly wash it with distilled water.
2. Wash the glass beaker and probe electrodes thoroughly with distilled water.
3. Fill the beaker with a 15 N sulphuric acid solution, and place the platinum-foil electrode in the beaker.
4. Adjust the variable resistor shown in figure A1-a for maximum resistance.

5. Connect both electrodes of the probe as shown in figure A1 and submerge the electrodes in the solution. After the electrodes are submerged, adjust the variable resistance until the meter indicates a current of 5 milliamperes.

6. Continue the cleaning process for approximately two minutes and then remove the electrodes and platinum-foil and wash them thoroughly with distilled water.

The steps involved in platinizing the probe electrodes are as follows:

1. Fill the glass beaker with chloroplatinic acid and install the platinum-foil and probe into the beaker.

2. Adjust the variable resistance to its maximum value and connect the electrodes as shown in figure A1-b.

3. Adjust the variable resistor until the meter indicates a current of 3 milliamperes. Stir the fluid gently for 30 seconds and then remove the electrodes and immerse them in distilled water for a period of two hours before using them. When the platinized electrodes are not in use, they should be stored in distilled water.

Inadequate platinizing is indicated if the response of the probe is sluggish to rapid changes of concentration. If this is observed, wash the probe in distilled water and replatinize as described above. If after usage the probe becomes sluggish, then clean and platinize as described in the above procedures.

II. PREPARATION OF THE 15 NORMAL (15 N) SULPHURIC ACID

Slowly pour one volume of concentrated (36 N) sulphuric acid into a 2.60 volumes of distilled water. Stir continuously while adding the concentrated sulphuric acid in order to avoid an explosion.

The solution will get very hot as a consequence of the exothermic reaction.

III. PREPARATION OF THE CHLOROPLATINIC ACID

Dissolve 1/8 oz. (3.45 g.) of chloroplatinic acid (platinic chloride crystal) and 20 mg. of lead acetate (crystal) in 100 cc. of distilled water. The platinic chloride crystals must not be exposed to air before use because they are very hygroscopic. Similarly, the prepared solution must be kept in a tightly closed container when not in use.

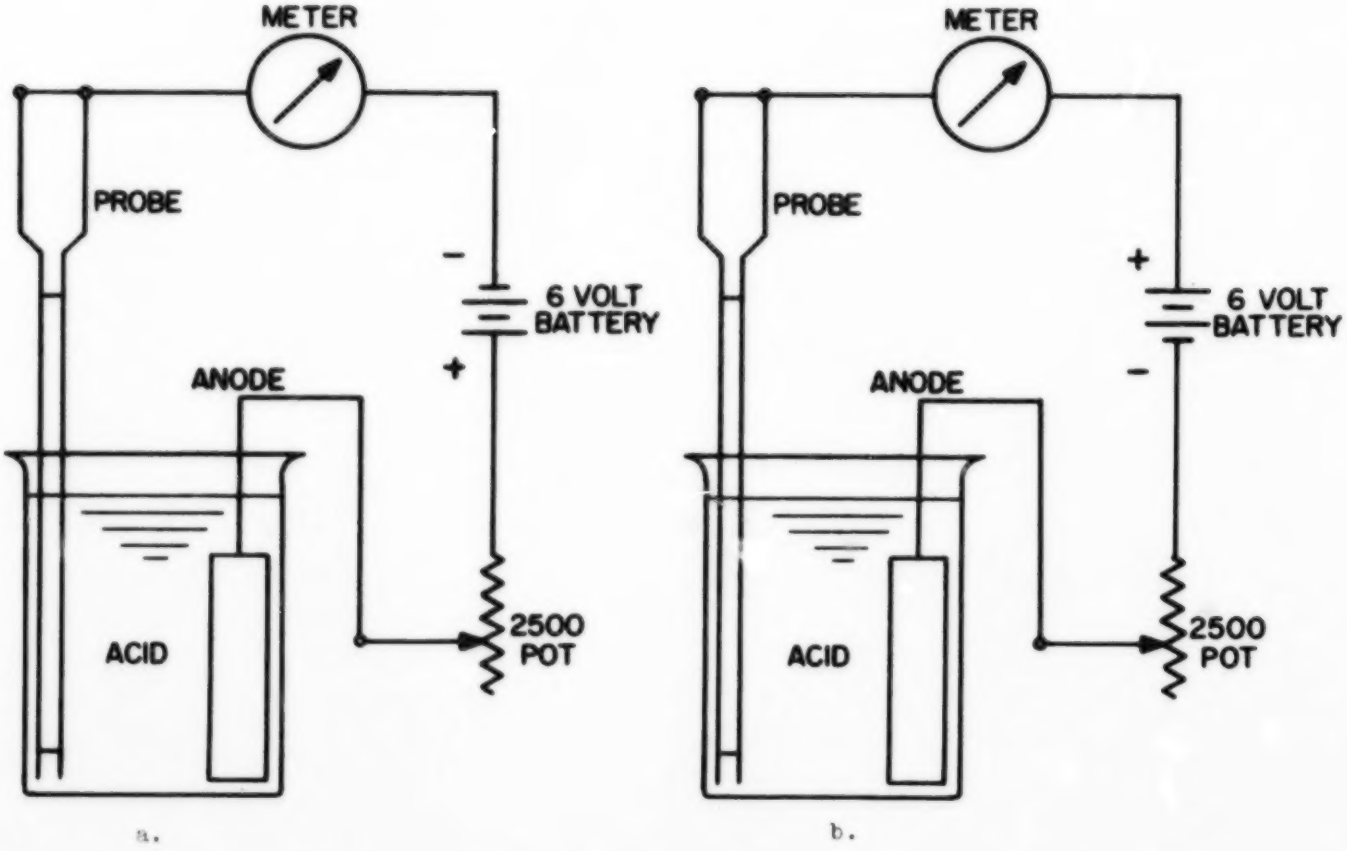

Figure A1. Circuits For Cleaning and Platinizing The Electrodes